

# Optical Monitoring of the Seyfert Galaxy NGC 4151 and Possible Periodicities in the Historical Light Curve

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**Abstract** We report *B*, *V*, and *R* band CCD photometry of the Seyfert galaxy NGC 4151 obtained with the 1.0 m telescope at Weihai Observatory of Shandong University and the 1.56 m telescope at Shanghai Astronomical Observatory from 2005 December to 2013 February. Combining all available data from literature, we have constructed a historical light curve from 1910 to 2013 to study the periodicity of the source using three different methods (the Jurkevich method, the Lomb-Scargle periodogram method and the Discrete Correlation Function method). We find possible periods of  $P_1 = 4 \pm 0.1$ ,  $P_2 = 7.5 \pm 0.3$  and  $P_3 = 15.9 \pm 0.3$  yr.

**Key words:** methods: data analysis – galaxies: active – galaxies: individual (NGC 4151)

## 1 INTRODUCTION

The nature of active galactic nuclei (AGNs) is an important and open question in astrophysics. Photometric observation of AGNs is an important tool for constructing their light curves and for studying the variability behavior over different time scales. Photometric observations have been made for a long time, so it is possible to search for periodicity in the light curves of a number of objects (e.g. Kidger et al., 1992; Liu et al., 1995; Fan et al., 1997, 1998, 2002a, 2010; Qian & Tao, 2004; Tao et al., 2008; Li et al., 2009). Based on the variability analysis, we can get much information about the physical mechanisms of AGNs. In addition, a confirmed periodicity would help us investigate the relevant physical parameters and limit the physical models in AGNs (Lainela et al., 1999).

NGC 4151 (Seyfert type 1.5) is one of the nearest ( $z = 0.00332$ ,  $D = 13.2$  Mpc when a Hubble constant of  $75 \text{ km s}^{-1} \text{ Mpc}^{-1}$  is used) and brightest Seyfert galaxies. It is also one of the best studied objects across the entire electromagnetic spectrum owing to its brightness and variability properties. The nucleus of this galaxy shows flux variability at a wide range of wavelength, with time scales from a few hours in the hard X-ray (Yaqoob et al., 1993) to several months in the infrared (Oknyanskij et al., 1999).

The photometric observations of NGC 4151 began as early as 1906. The nucleus of NGC 4151 was first discovered in 1967 as variable in optical region (Fitch et al., 1967), and the variability was confirmed by Zaitseva & Lyutyi (1969). Since then it has been intensively monitored by several monitoring campaigns (e.g. Clavel et al., 1990; Yaqoob et al., 1993; Kaspi et al., 1996). Optical variability time scales ranged from tens of minutes to decades were reported by many investigators (Lyutyi et al., 1989; Lyutyi, 1977; Lyutyj & Oknyanskij, 1987; Longo et al., 1996; Guo et al., 2006; Oknyanskij & Lyuty, 2007). Oknyanskij et al. (2012) pointed out that NGC 4151 has different variable components: fast variations with time scale about tens of days; slow variations with time scale about several years; very slow component with time scale about tens of years. NGC 4151 is one of the very few AGNs whose optical light curve data spans more than a century, so it provides us a very good opportunity to analyze its periodicity.

In this work, we present optical (*BVR*) observations over 7.2 years using the 1.0 m telescope at Weihai Observatory of Shandong University and 1.56 m telescope at Shanghai Astronomical Observatory (SHAO). In section 2, we give a description of our observations and data processing. Then in sections 3 and 4, we present the light curves and the periodicity analysis. Discussions and conclusions are given in section 5.

## 2 OBSERVATIONS AND DATA REDUCTION

From 2005 December to 2013 February, 1587 observations were obtained on 22 nights using the 1.0m telescope at Weihai Observatory of Shandong University (observed from 2009 May to 2013 February) and the 1.56m telescope at Sheshan Station of Shanghai Astronomical Observatory (observed from 2005 December to 2008 February). The seeing at Weihai usually varies from  $1.2''$  to  $2.5''$ . The one-meter Cassegrain telescope at Weihai Observatory was equipped with a back illuminated PIXIS 2048B CCD camera from the Princeton Instruments company and a standard Johnson/Cousins set of *UBVRI* filters controlled

by a dual layer filter wheel from American Astronomical Consultants and Equipment Inc. (ACE). The PIXIS camera has  $2048 \times 2048$  square pixels and the pixel size is  $13.5\mu\text{m}$ . The scale of the image is about  $0.35''$  per pixel and the field of view is about  $11.8' \times 11.8'$ . Readout noise and gain of this CCD detector is 3.64 electrons and 1.65 electrons/ADU, respectively, for slow readout and low-noise output setup. The standard Johnson and Cousins filters ( $B$ ,  $V$ , and  $R$ ) were used during our observations. For each observing night, twilight sky flats were taken, several bias frames were taken at the beginning of the observation. All data were processed by bias and flat-field correction. The instrumentation and data reduction information for SHAO is the same as Guo et al. (2006). The task APPHOT of the IRAF software package was used to do the photometry. Comparison stars 2 and 3 taken from Penston et al. (1971) were used for calibration. An aperture radius about  $13''$  was adopted, which was larger enough than the minimum aperture recommended by Cellone et al. (2000). Then we were able to derive magnitude of the source by differential photometry. The error is given as below

$$\sigma = \sqrt{(m_2 - \bar{m})^2 + (m_3 - \bar{m})^2}, \quad (1)$$

where  $m_2$  and  $m_3$  is the magnitude of NGC 4151 calibrated by the 2th and 3th comparison star respectively, whereas  $\bar{m}$  is the mean magnitude of the object obtained from the comparison stars.

### 3 LIGHT CURVES

Panel a, b and c in Fig. 1 shows the light curves of NGC 4151 and the magnitude difference between comparison stars 2 and 3 in  $B$ ,  $V$ , and  $R$  band, respectively. Different constants were added to the corresponding differential magnitudes of the comparison stars for clarity. During our observations, variations of 0.669 mag (12.199 to 12.868) in  $B$  band, 0.964 mag (11.542 to 12.506) in  $V$  band, and 0.451 mag (10.875 to 11.326) in  $R$  band were detected. Our observations in  $V$  band illustrates that NGC 4151 was decreasing in its brightness from the beginning of our campaign and reached its minimum in 2008 February, then it began to brighten and reached its maximum in 2011 April, finally it declined slowly in brightness again on the whole with some fluctuations. The light curve can be roughly fitted by a sine function during our 7.2 years observation period, but more data are needed to confirm whether this periodicity is real. The patterns of optical variability in these three bands are similar.

In order to detect the microvariability, both C test (Jang & Miller, 1997; Diego, 2010) and F test (Diego, 2010; Gaur et al., 2012) tests have been performed on those 10 out of 22 nights when we have more than five observations in the three bands simultaneously. However, no significant microvariability was detected during our observations.

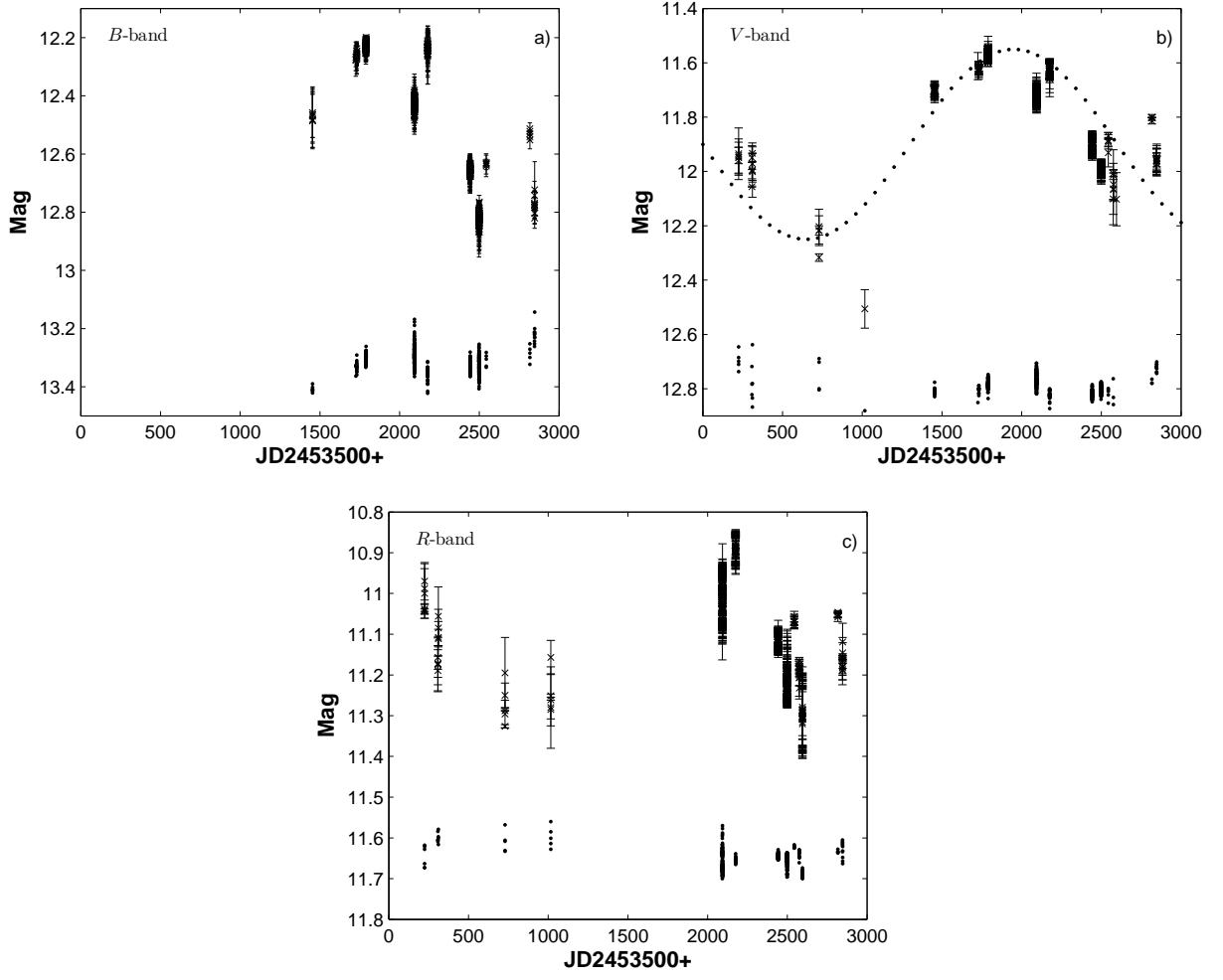
### 4 PERIODICITY ANALYSIS

Many authors have investigated the variability periodicity of NGC 4151. Oknyanskij (1983) suggested a possible period of 16 yr using data from Pacholczyk (1971). Lyutyi & Oknyanskij (1987) found periods of 4 and 14 yr using the method of Deeming (1975) to a set of about 400 photoelectric data. No evident periodicity was found by Longo et al. (1996). Fan & Su (1999) obtained a period of  $14.08 \pm 0.8$  yr using the Jurkevich method. Oknyanskij & Lyutyi (2007) found a periodic component about 15.6 years using the Fourier (CLEAN) algorithm. Oknyanskij et al. (2012) suggested that NGC 4151 has different long-term variable time scales ranged from several years to tens of years, so we have reconstructed the historical light curve by combining our own observations with data in the literature (Zaitseva & Lyutyi, 1969; Lyutyi, 1973, 1977; Belokon et al., 1978; Lyutyi & Doroshenko, 1999; Doroshenko et al., 2001; Oknyanskij et al., 2012; Roberts & Rumstay, 2012) and the raw photographic data as early as 1910 to research periodicity. The long-term light curve in  $B$  band was shown in Fig. 2. The data used in this paper are mainly from Lyutyi & Doroshenko (1999), Doroshenko et al. (2001) and Oknyanskij et al. (2012). These data are consistent with each other and they are from many published data. Their data set was called Crimean series subsequently. We found that the data derived from Roberts & Rumstay (2012) was about 0.35 mag fainter compared with Crimean data which overlaid on the same day. Unfortunately, Our data didn't overlap with Crimean data set. However, we noticed that for Crimean data set, the brightness of NGC 4151 remained nearly constant between JD 2456042 and JD 2456044, and we just had observations on JD 2456043. Further more, no microvariability was detected during our observations. So a linear interpolation can be used to combine our data with the Crimean data. A constant about 0.25 mag was subtracted in order to combine our data with theirs.

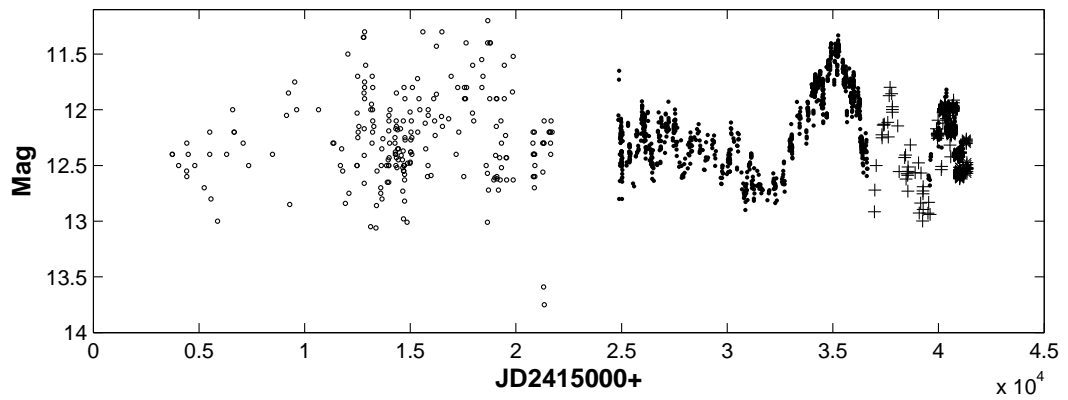
In order to give more uniform weighting to different epochs, we carried out a 10-day averaging for all the available data. This bin size is short enough compared with the long-term periods which we are looking for (years) and thus unlikely to distort long-term variations.

#### 4.1 Jurkevich Method

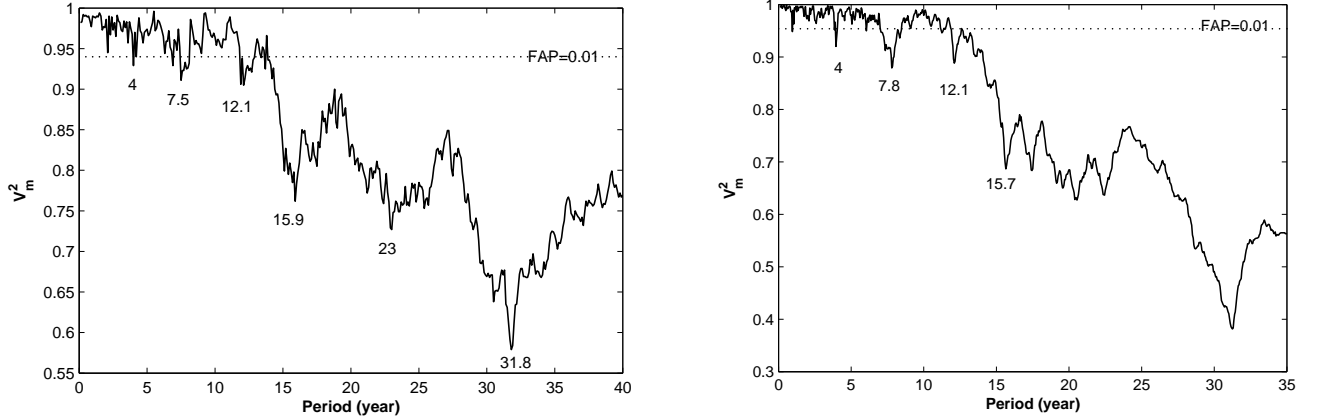
The Jurkevich method (JV)(Jurkevich, 1971) is based on the expected mean square deviation. It does not require an equally spaced observations, so it is less inclined to generate a spurious periodicity compared to a Fourier analysis. It tests a series of trial periods and the data are folded according to the trial periods. Then all data are divided into  $m$  groups according to their phases around each trial period. The variance  $V_i^2$  for each group and the sum of each group variance  $V_m^2$  are computed. If a



**Fig. 1** Light curve of NGC 4151. x-marks denote  $B$ ,  $V$ , and  $R$  band Light curve of NGC 4151. Dots denote the magnitude difference of the comparison stars 2 and 3 (constants were added). Dotted line in panel b is the fitted sine function for  $V$  band data.



**Fig. 2** Historical light curve of NGC 4151 from 1910 to 2013 in  $B$  band. Dots denote the Crimean series data, circles denote the raw photographic data, pluses denote the data from Roberts & Rumstay (2012) and stars denote our observations.



**Fig. 3** Relationship between the trial period and  $V_m^2$ . Plot in the left panel and right panel was derived by using all the available data and the post-1968 data, respectively.

trial period equals to the real one, then  $V_m^2$  would reach its minimum. The detailed computation of the variances is described in Jurkevich (1971). In order to estimate the reliability of the period, Kidger et al. (1992) introduced a parameter,

$$f = \frac{1 - V_m^2}{V_m^2}, \quad (2)$$

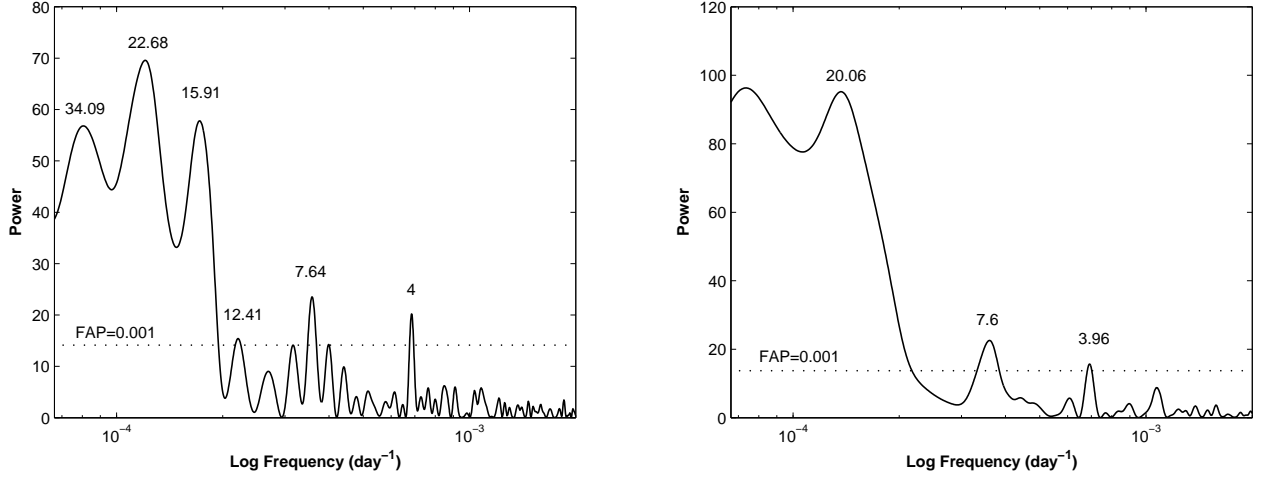
where  $V_m^2$  is a normalized value. In the normalized plot, a value of  $V_m^2 = 1.0$  means that  $f = 0$ , hence there is no periodicity at all. The possible periods can be easily obtained from the plot. In general, if  $f \geq 0.5$ , it suggests that there is a strong periodicity in the data; if  $f \leq 0.25$ , usually indicates that the periodicity, if genuine, is a weak one. A further test is the relationship between the depth of the minimum and the noise in the “flat” section of the  $V_m^2$  curve close to the detected period (Kidger et al., 1992; Fan et al., 2006). Fan et al. (2010) pointed out that this method is not good enough to give a quantitative criterion and the False Alarm Probability (FAP, Horne & Baliunas, 1986) can deal with all kinds of periodicity analysis methods if the variations (mainly) consist of randomly distributed noise. So we adopted FAP to give a quantitative criterion (see Fan et al., 2010; Chen et al., 2014) for the detected periods. One should also keep in mind the confidence level derived by this method tends to be overestimated. Because the independent random values were used to evaluate the statistical significance of periods and it may neglected the fact that the dependent random values existed in the light curves of AGNs.

The results by the Jurkevich method with  $m=5$  are shown in the left panel of Fig. 3. and there are no significant differences when  $m=10$  was used. FAP level of 0.01 is also marked in the figure derived from Monte Carlo method as proposed by Fan et al. (2010). From the figure, there are several obvious minimum values for  $V_m^2$  whose FAP is smaller than 0.01, indicating possible periods in the trial. The first minimum of  $V_m^2 = 0.92$  is at the period  $P_1 = 4 \pm 0.1$  yr. it is consistent with the result of 4 yr found by Lyutyi & Oknyanskij (1987). The second minimum of  $V_m^2 = 0.91$  is corresponding to  $P_2 = 7.5 \pm 0.3$  yr. The third minimum of  $V_m^2 = 0.9$  is corresponding to  $P_3 = 12.1 \pm 0.2$  yr. The fourth minimum of  $V_m^2 = 0.76$  is corresponding to  $P_4 = 15.9 \pm 0.3$  yr. The fifth minimum of  $V_m^2 = 0.72$  is corresponding to  $P_5 = 23 \pm 0.3$  yr and the sixth minimum of  $V_m^2 = 0.58$  is corresponding to  $P_6 = 31.8 \pm 0.2$  yr. We note that those periods have the following simple relationships:  $P_3 \approx 3P_1$ ,  $P_5 \approx 3P_2$  and  $P_6 \approx 2P_4$ .

From Fig. 2, one can see a large gap between JD. 2436717 and JD. 2439849 which may strongly affect the sensitivity of the method and result in the appearance of false period. So we apply both the Jurkevich method and the Monte Carlo method to the more homogeneous data set after 1968 (beginning from JD. 2439849, called post-1968 data hereafter) to calculate the periodicity and FAP (0.01). The results are shown in the right panel of Fig. 3. One can see from the right panel of Fig. 3 that there are several obvious minimum values for  $V_m^2$  whose FAP is smaller than 0.01. Taking the shorter time span (only about 45 years observation) which was less than six times of the period (Kidger et al., 1992) into consideration, the periods larger than ten years were ruled out. The periods of  $4 \pm 0.1$  and  $7.8 \pm 0.4$  yr found in the right panel are in good agreement with the periods of  $P_1 = 4 \pm 0.1$  and  $P_2 = 7.5 \pm 0.3$  yr found in the left panel of Fig. 3, respectively.

#### 4.2 Lomb-Scargle Periodogram Method

In order to investigate the reliability of these results, we also performed the Lomb-Scargle normalized periodogram (LS) to analyze the periodicity. The Lomb-Scargle normalized periodogram (Lomb, 1976; Scargle, 1982; Press et al., 1994) is a powerful method which can be applied to the periodicity analysis of random and unevenly sampled observations.



**Fig. 4** Results of Lomb-Scargle method for NGC 4151. Power curve in the left panel and right panel was calculated using all the available data and the post-1968 data, respectively. Dotted lines denote the false alarm probability of 0.001.

For a time series  $X(t_k)$  ( $k = 0, 1, \dots, N_0$ ), the periodogram as a function of frequency  $\omega$ , is defined as

$$P_x(\omega) = \frac{1}{2} \left\{ \frac{[\sum_i X(t_i) \cos \omega(t_i - \tau)]^2}{\sum_i \cos^2 \omega(t_i - \tau)} + \frac{[\sum_i X(t_i) \sin \omega(t_i - \tau)]^2}{\sum_i \sin^2 \omega(t_i - \tau)} \right\}, \quad (3)$$

where  $\tau$  is defined by the formula

$$\tau = \frac{1}{2\omega} \tan^{-1} \left[ \frac{\sum_i \sin 2\omega t_i}{\sum_i \cos 2\omega t_i} \right]. \quad (4)$$

Here and throughout,  $\omega$  is the angular frequency and  $\omega = 2\pi\nu$ , so the periodogram is also a function of the frequency  $\nu$ . According to the definition of  $P_x(\omega)$ , the power in  $P_x(\omega)$  would follow an exponential probability distribution if the signal  $X(t_k)$  is purely noise. This exponential distribution provides a convenient estimate for the probability that a given peak is a real signal, or it is only the result of randomly distributed noise. For a power level  $z$ , FAP is calculated as (see Scargle, 1982; Press et al., 1994)

$$p(> z) \approx N \cdot \exp(-z), \quad (5)$$

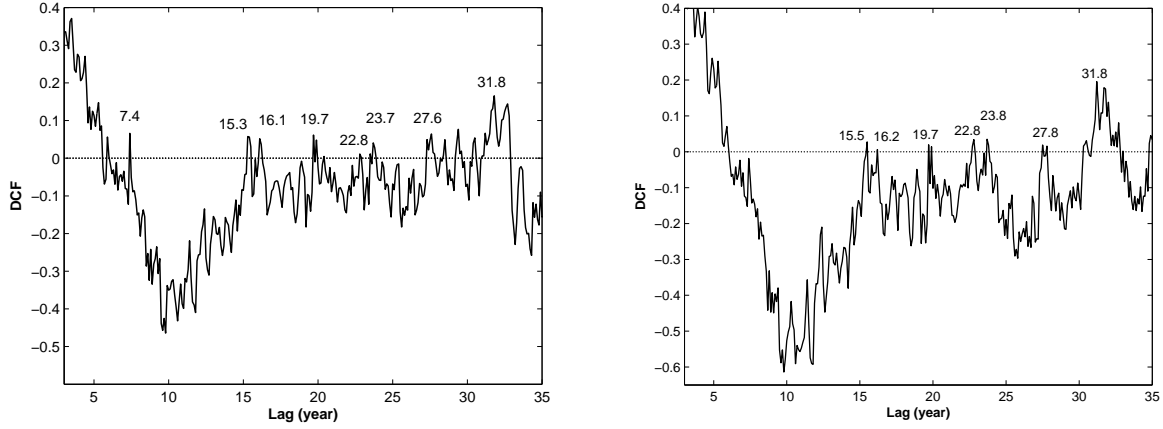
where  $N$  is the number of frequencies searched for the maximum.  $N$  is very nearly equal to the number of data points  $N_0$  when the data points are approximately equally spaced and the estimate of  $N$  needs not be very accurate (Press et al., 1994), and the half width at half maximum (HWHM) of the peak can be used to estimate the corresponding periodic error.

The results of Lomb-Scargle Periodogram and false alarm probability are shown in Fig. 4. Power curves in the left panel and in the right panel were calculated using all the available data and the post-1968 data, respectively. From the left panel of Fig. 4, we could find several peaks ( $P_1 = 4 \pm 0.2$ ,  $P_2 = 7.64 \pm 0.3$ ,  $P_3 = 12.41 \pm 0.6$ ,  $P_4 = 15.91 \pm 0.9$ ,  $P_5 = 22.68 \pm 1.6$ ,  $P_6 = 34.09 \pm 3.2$ ) whose false alarm probability are smaller than 0.001. For the results of  $P_2$ ,  $P_3$ ,  $P_4$ ,  $P_5$ ,  $P_6$ , we note that  $P_5 \approx 3P_2$ ,  $P_4 \approx 4P_1$ ,  $P_3 \approx 3P_1$ . The periods found by the Lomb-Scargle Periodogram are in good agreement with the results found by the Jurkevich method using all the available data. We also apply the Lomb-Scargle Periodogram to the post-1968 data to calculate the periodicity and the results are shown in the right panel of Fig. 4. The periods of  $3.96 \pm 0.1$  and  $7.6 \pm 0.4$  yr is corresponding to  $P_1 = 4 \pm 0.1$  and  $P_2 = 7.5 \pm 0.3$  yr found by Jurkevich method using the same data set, respectively.

### 4.3 Discrete Correlation Function Method

For comparing and further investigating the reliability of these periods, we have performed the Discrete Correlation Function (DCF) method to analyze the periodicity. The DCF method, introduced by Edelson & Krolik (1988), can be used to analyze unevenly sample variability data, with the advantage of no interpolation of data. It can be done as follows. Firstly, we calculate the set of unbinned discrete correlation function (UDCF) of all measured pairs  $(a_i, b_j)$ , i.e.

$$UDCF_{ij} = \frac{(a_i - \bar{a})(b_j - \bar{b})}{\sigma_a \sigma_b}, \quad (6)$$



**Fig. 5** Results of the Discrete Correlation Function method for NGC 4151. DCF curve in the left panel and right panel was obtained using all the available data and the post-1968 data, respectively.

where  $\bar{a}$  and  $\bar{b}$  are the average values of the data sets,  $\sigma_a$  and  $\sigma_b$  are the corresponding standard deviations. Secondly, We averaged the points sharing the same time lag  $\tau$  by binning the  $UDCF_{ij}$  in the suitable sized time-bins, then  $DCF(\tau)$  can be calculated as following,

$$DCF(\tau) = \frac{1}{M} \sum UDCF_{ij}(\tau), \quad (7)$$

where  $M$  is the number of pairs satisfying  $\tau - \Delta\tau/2 \leq \Delta t_{ij} < \tau + \Delta\tau/2$ . Then, the standard error for each time lag  $\tau$  is

$$\Delta\tau = \frac{1}{M-1} \left\{ \sum [UDCF_{ij} - DCF(\tau)]^2 \right\}^{0.5}. \quad (8)$$

In general, a positive peak constitutes a possible period and the height of the peak indicates the periodicity strength (Hufnagel & Bregman, 1992). The results of DCF are displayed in Fig. 5. DCF curve in the left panel and right panel was obtained using all the available data and the post-1968 data, respectively. Several possible periods, estimated from positive peaks in the DCF, are  $7.4 \pm 0.1$ ,  $15.3 \pm 0.2$ ,  $16.1 \pm 0.2$ ,  $19.7 \pm 0.3$ ,  $22.8 \pm 0.3$ ,  $23.7 \pm 0.3$ ,  $27.6 \pm 0.3$  and  $31.8 \pm 0.2$  yr for the left panel of Fig. 5;  $15.5 \pm 0.2$ ,  $16.2 \pm 0.3$ ,  $19.7 \pm 0.3$ ,  $22.8 \pm 0.3$ ,  $23.8 \pm 0.4$ ,  $27.8 \pm 0.4$  and  $31.8 \pm 0.2$  yr for the right panel. One can note that the periods found by DCF methods have multiple frequency relationships with the periods of  $P_1 = 4 \pm 0.1$ ,  $P_2 = 7.5 \pm 0.3$  or  $P_3 = 15.9 \pm 0.3$  yr found by Jurkevich method.

#### 4.4 Results

From the analyses of the results given above, we summarise the main periods in Table 1. For the periods of  $P_1$ ,  $P_2$ ,  $P_3$ ,  $P_4$ ,  $P_5$  and  $P_6$  discerned by the Jurkevich method and the Lomb-Scargle Periodogram (see Table 1), one can note that there exists a simple relationship:  $P_3 \approx 4P_1$ ,  $P_4 \approx 3P_1$ ,  $P_5 \approx 3P_2$  and  $P_6 \approx 3P_3$ . According to the result by Kidger et al. (1992), the period of  $P_1 = 4 \pm 0.1$  yr found by the Jurkevich method is a week one, whereas  $P_3 = 15.9 \pm 0.3$  yr is strong periodicity. At the same time, Oknyanskij & Lyuty (2007), Bon et al. (2012) also found a possible period of around 16 yr using different methods and data, so we think that the period  $P_1 = 4 \pm 0.1$  and  $P_3 = 15.9 \pm 0.3$  yr have different origin, although they have an astronomical multiple frequency relationship  $P_3 \approx 4P_1$ . For a further comparison, we used the DCF method for periodicity analysis. However, there is no sign of 4 yr period in the DCF analysis, this may be due to that the period of  $P_1$  is a weak one. Further more the DCF analysis will dilute the sign of other periods if more than one period is present (Fan et al., 2006). Although there is no sign of 4 yr period in the results of DCF method, it is interesting to note that the periods of  $19.7 \pm 0.3$ ,  $23.7 \pm 0.3$  and  $27.6 \pm 0.3$  yr are about 5, 6, and 7 times of the 4 yr (see Fig. 5), respectively. It implies that they have an astronomical multiple frequency relationship. Based on the analysis above, we think that the period of  $4 \pm 0.1$  yr is existent indeed. Taking into account that our light curve in V band can be roughly fitted by a 7.1-year sine function, which is consistent with the period of  $P_2 = 7.5 \pm 0.3$  yr, so the possible periods found by the three methods are  $P_1 = 4 \pm 0.1$ ,  $P_2 = 7.5 \pm 0.3$  and  $P_3 = 15.9 \pm 0.3$  yr.

## 5 DISCUSSION AND CONCLUSIONS

The variability mechanism of AGNs is not yet well understood and some models have been proposed to explain the possible optical long-term periodic variations: the binary black hole model, the disk-instability model and the perturbation model. As



**Table 1** Periodicity Analysis Results

	$P_1(\text{yr})$	$P_2(\text{yr})$	$P_3(\text{yr})$	$P_4(\text{yr})$	$P_5(\text{yr})$	$P_6(\text{yr})$
JV <sup>◇</sup>	$4 \pm 0.1$	$7.5 \pm 0.3$	$15.9 \pm 0.3$	$12.1 \pm 0.2 (3P_1)$	$23 \pm 0.3 (3P_2)$	$31.8 \pm 0.2 (2P_3)$
JV(post-1968)*	$4 \pm 0.1$	$7.8 \pm 0.4$				
LS <sup>◇</sup>	$4 \pm 0.2$	$7.64 \pm 0.3$	$15.91 \pm 0.9$	$12.1 \pm 0.6 (3P_1)$	$22.68 \pm 1.6 (3P_2)$	$34.09 \pm 3.2 (2P_3)$
LS (post-1968)*	$3.96 \pm 0.1$	$7.6 \pm 0.4$				
DCF <sup>◇</sup>		$7.4 \pm 0.1$	$16.1 \pm 0.2$		$22.8 \pm 0.3 (3P_2)$	$31.8 \pm 0.2 (2P_3)$
DCF (post-1968)*			$16.2 \pm 0.3$		$22.8 \pm 0.2 (3P_2)$	$31.8 \pm 0.2 (2P_3)$

◇ Using all the available data.

\* Using photoelectric and CCD observational data after 1968.

for NGC 4151, Aretxaga & Terlevich (1994) found that the long term variability of NGC 4151 can be well described by the starburst model. However, it had difficulty in explaining the short timescale of the optical variability and the extreme energetics (Gopal-Krishna et al., 2000). Fan et al. (2002b) adopted the structure function to *B* band data to discuss the emission origin in the Seyfert galaxy NGC 4151 and the result favored the disk instability model. Czerny et al. (2003) concluded that the long time scale variability may be caused by radiation pressure instability in the accretion disc by analysis of the 90 yr of the optical data and 27 yr of the X-ray data using the normalized power spectrum density (NPSD) and the structure function. Lyuty (2005) found that the pattern of ultraviolet and optical variability in NGC 4151 agreed excellently with the theory of disk accretion instability for a supermassive black hole suggested by Shakura & Sunyaev (1973). Oknyanskij & Lyuty (2007) thought the 14-16 years circles seen in the light curve probably correspond to some accretion dynamic time. Analysis by Bon et al. (2012) showed that periodic variations in the light curve and radial velocity curve can be accounted for an eccentric, sub-parsec Keplerian orbit of a 15.9 yr period.

The historical light curve of NGC 4151 showed strong variability and three possible periods were found by different periodicity analysis methods. The periods of  $P_1 = 4 \pm 0.1$ ,  $P_2 = 7.5 \pm 0.3$  and  $P_3 = 15.9 \pm 0.3$  yr are consistent with the findings by Oknyanskij et al. (2012) that NGC 4151 has different long-term variable time scales ranged from several to tens of years. The period of  $P_1 = 4 \pm 0.1$  yr is in good agreement with the result found by Lyutyi & Oknyanskij (1987), and the period of  $P_3 = 15.9 \pm 0.3$  yr is also consistent with the results found by many investigators (Oknyanskij, 1983; Guo et al., 2006; Oknyanskij & Lyuty, 2007; Bon et al., 2012). The multiple periods we derived may imply the instabilities in the disk.

In our monitoring program, we have observed NGC 4151 from 2005 December to 2013 February. The observations clearly show that the source is variable in the optical band with the variation amplitudes of 0.669 mag, 0.964 mag and 0.451 mag in *B*, *V*, and *R* bands, respectively. The *B* band historical light curve is constructed, which has a time span of 103 yr. Possible periods of  $P_1 = 4 \pm 0.1$ ,  $P_2 = 7.5 \pm 0.3$  and  $P_3 = 15.9 \pm 0.3$  yr were found in the light curve by adopting the Jurkvech method, the Lomb-Scargle Periodogram method and the DCF method.

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## References

- Aretxaga, I., & Terlevich, R. 1994, MNRAS, 269, 462  
 Belokon, E. T., Badadzhanians, M. K., Liutyi, V. M. 1978, A&AS, 31, 383  
 Bon, E., Jovanović, P., Marziani, P., et al. 2012, ApJ, 759, 118  
 Cellone, S. A., Romero, G. E., & Combi, J. A. 2000, AJ, 119, 1534  
 Chen, X., Hu, S. M., Guo, D. F., & Du, J. J. 2014, Ap&SS, 2014, 349, 909  
 Clavel, J., Boksenberg, A., Bromage, G. E., et al. 1990, MNRAS, 246, 668  
 Czerny, B., Doroshenko, V. T., Nikolajuk, M., Schwarzenberg-Czerny, A., Loska, Z., Madejski, G. 2003, MNRAS, 342, 1222  
 Deeming, T. J. 1975, Ap&SS, 36, 137  
 de Diego., 2010, AJ, 139, 1269  
 Doroshenko, V. T., Lyutyi, V. M., et al. 2001, A&L, 27, 65  
 Edelson, R. A., & Krolik, J. H. 1988, ApJ, 333, 646  
 Fan, J. H., Xie, G. Z., Lin, R. G., et al. 1997, A&AS, 125, 525  
 Fan, J. H., Xie, G. Z., Pecontal, E., Pecontal, A., & Copin, Y. 1998, ApJ, 507, 173  
 Fan, J. H., & Su, C. Y. 1999, ChA&A, 23, 22  
 Fan, J. H., Lin, R. G., Xie, G. Z., et al. 2002a, A&A, 381, 1  
 Fan, J. H., Su, C. Y., & Lin, R. G. 2002b, PASJ, 54, 175  
 Fan, J. H., Tao, J., Qian, B. C., et al. 2006, PASJ, 58, 797

- Fan, J. H., Liu, Y., Qian, B. C., et al. 2010, RAA, 10, 1100
- Fitch, W. S., Pacholczyk, A. G., Weymann, R. J., et al. 1967, ApJ, 150, 67
- Gaur, H., Gupta, A. C., Wiita, P. J. 2012, AJ, 143, 23
- Gopal-Krishna, Gupta, A. C., Sagar, R., et al. 2000, MNRAS, 314, 815
- Guo, D. F., Tao, J., & Qian, B. C. 2006, PASJ, 58, 503
- Horne, J., & Baliunas, S. 1986, ApJ, 302, 757
- Hufnagel, B. R. & Bregman, J. N. 1992, ApJ, 386, 473
- Jang, M., & Miller, H. R. 1997, AJ, 114, 565
- Jurkevich, I. 1971, Ap&SS, 13, 154
- Kaspi, S., Maoz, D., Netzer, H., Peterson, B. M., et al. 1996, ApJ, 470, 336
- Kidger, M. R., Takalo, L., & Sillanpää, A. 1992, A&A, 264, 32
- Lainela, M. Takalo, L. O., Sillanpää, A., et al. 1999, ApJ, 521, 561
- Li, H. Z., Xie, G. Z., Zhou, S. B., et al. 2009, PASP, 121, 1172
- Liu, F. K., Xie, G. Z., & Bai, J. M. 1995, A&A, 295, 1
- Lomb, N. R. 1976, Ap&SS, 39, 447
- Longo, G., Vio R., Paura, P., Provenzale, A., & Rifatto, A. 1996, A&A, 312, 424
- Lyuty, V. M. 2005, AstL, 31, 645
- Lyutyi, V. M. 1973, SvA, 16, 763
- Lyutyi, V. M. 1977, SvA, 21, 655
- Lyutyi, V. M., & Oknyanskij, V. L. 1987, SvA, 31, 245
- Lyutyi, V. M., Aslanov, A. A., Khruzina, T. S., Kolosov, D. E., Volkov, I. M. 1989, SvAL, 15, 247
- Lyutyi, V. M., & Doroshenko, V. T. 1999, AstL, 25, 341
- Lyutyj, V. M., & Oknyanskij, V. L. 1987, AZh, 64, 465
- Oknyanskij, V. L. 1983, ATsir, 1300, 1
- Oknyanskij, V. L., Lyuty, V. M., Taranova, O. G., Shenavrin, V. I. 1999, AstL, 25, 483
- Oknyanskij, V. L., & Lyuty, V. 2007, PZP, 7, 28
- Oknyanskij, V. L., Metlova, N., Artamonov, B., Ezhkova, O., Lyuty, A., Lyuty, V. 2012, OAP, 25, 179
- Pacholczyk, A. G. 1971, ApJ, 163, 449
- Penston, M. J., Penston, M. V., & Sandage, A. 1971, PASP, 83, 783
- Press, W. H., et al. 1994, Numerical Recipes in FORTRAN (2nd ed.,; Cambridge: Cambridge Univ. Press)
- Qian, B. C., & Tao, J. 2004, PASP, 116, 161
- Roberts, C. A., & Rumstay, K. R. 2012, JSARA, 6, 47
- Scargle, J. D. 1982, ApJ, 263, 835
- Shakura, N. I., & Sunyaev, R. A. 1973, A&A, 24, 337
- Tao, J., Fan, J. H., Qian, B. C., & Liu, Y. 2008, AJ, 135, 737
- Yaqoob, T., Warwick, R. S., Makino, F., Otani, C., Sokoloski, J. L., Bond, I. A., & Yamauchi, M. 1993, MNRAS, 262, 435
- Zaitseva, G. V., & Lyutyi, V. M. 1969, SvA, 13, 184